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Transmitted herewith for filing is the patent application of
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For: IN-PLANE SWITCHING LIQUID CRYSTAL
DISPLAY DEVICE

Enclosed are:

- (X) 27 pages of specification, including 21 claims and an abstract.
- (X) an executed oath or declaration, with power of attorney.
- () an unexecuted oath or declaration, with power of attorney.
- () _____ sheet(s) of informal drawing(s).
- (X) 13 sheet(s) of formal drawings(s).
- (X) Assignment(s) of the invention to Fujitsu Limited.
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- (X) Priority Document.

Fee Calculation For Claims As Filed

a) Basic Fee						\$ 760.00
b) Independent Claims	<u>5</u>	-	<u>3</u>	=	<u>2</u>	x \$ 78.00 = \$ <u>156.00</u>
c) Total Claims	<u>21</u>	-	<u>20</u>	=	<u>1</u>	x \$ 18.00 = \$ <u>18.00</u>
d) Fee for Multiple Claims						\$260.00 = \$ _____
Total Filing Fee						\$ <u>934.00</u>

- () _____ Statement(s) of Status as Small Entity, reducing Filing Fee by half to \$ _____
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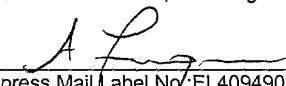
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SPECIFICATION

TO ALL WHOM IT MAY CONCERN:

BE IT KNOWN THAT WE, Yohei Nakanishi, a citizen of Japan residing at Kawasaki-shi, Kanagawa, Japan, Seiji Tanuma, a citizen of Japan residing at Kawasaki-shi, Kanagawa, Japan and Takatoshi Mayama, a citizen of Japan residing at Kawasaki-shi, Kanagawa, Japan have invented certain new and useful improvements in

IN-PLANE SWITCHING LIQUID CRYSTAL DISPLAY DEVICE

of which the following is a specification : -

1 TITLE OF THE INVENTION

 IN-PLANE SWITCHING LIQUID CRYSTAL DISPLAY
DEVICE

5 BACKGROUND OF THE INVENTION

 The present invention generally relates to
liquid crystal display devices and more particularly
to an in-plane switching liquid crystal display
device. An in-plane switching liquid crystal display
10 device is a device driven by an electric field acting
parallel to the liquid crystal layer forming the
liquid crystal display device.

 Conventionally, driving of a liquid crystal
display device has been achieved by applying an
15 electric field to a liquid crystal layer confined by a
pair of substrates such that the electric field acts
perpendicularly to the liquid crystal layer. On the
other hand, there is a proposal of a so-called in-
plane switching (IPS) liquid crystal display device,
20 in which an electric field is applied to the liquid
crystal layer such that the electric field acts in the
direction parallel to the substrates. In such an IPS
liquid crystal display device, an interdigital
electrode is provided on one of the foregoing
25 substrates.

 FIGS.1A and 1B show the principle of such an
IPS liquid crystal display device.

 Referring to FIG.1A, a liquid crystal layer
13 containing therein liquid crystal molecules is
30 confined between a pair of mutually opposing glass
substrates 11 and 12 in such a manner that the liquid
crystal layer makes an intimate contact with a
molecular alignment film 11A covering the substrate 11
and also an intimate contact with a molecular
35 alignment film 12A covering the substrate 12.
Further, polarizers 11B and 12B are disposed at
respective outer sides of the glass substrates 11A and

1 11B in a crossed Nicol state. Further, a pair of
electrodes 14A and 14B are provided on the glass
substrate 11 in a state that the electrodes 14A and
14B are covered by the molecular alignment film 11A.

5 In the non-activated state of FIG.1A, there
is no driving voltage applied across the electrodes
14A and 14B and the liquid crystal molecules 13A of
the liquid crystal layer 13 are aligned in a
predetermined direction in a plane generally parallel
10 to the substrates 11 and 12.

In the activated state of FIG.1B, on the
other hand, a driving voltage is applied across the
electrodes 14A and 14B, and an electric field is
induced in the liquid crystal layer 13 in the
15 direction generally parallel to the liquid crystal
layer 13. As a result of the electric field, the
direction of the liquid crystal molecules 13A, or
molecular orientation, is changed. An IPS liquid
crystal display device achieves the desired optical
20 switching by using such a change of the molecular
orientation of the liquid crystal molecules 13A. Due
to the fact that the change of the molecular
orientation occurs in the plane parallel to the liquid
crystal layer 13, an IPS liquid crystal display device
25 generally provides a superior viewing angle as
compared with the conventional twist-nematic (TN)
liquid crystal display devices.

On the other hand, such an IPS liquid
crystal display device, lacking an electrode on the
30 opposing substrate 12 contrary to a conventional TN
liquid crystal display device, tends to induce
polarization in the molecular alignment film 12A,
while such a polarization induced in the molecular
alignment film 12A tends to cause the problem of image
35 sticking or afterimage, in which the represented image
tends to remain after the image has been changed.
This problem of image sticking becomes particularly

1 acute when the liquid crystal display device is used
to display an image for a prolonged time period.

In order to eliminate the problem of image
sticking, it is necessary to use a low-resistance
5 liquid crystal having a resistance lower than the
resistance of the liquid crystal used in a
conventional TN liquid crystal display device, for the
liquid crystal layer 13. However, such a liquid
crystal having a low resistance generally has a large
10 dielectric constant and tends to dissolve impurities.
In other words, a low-resistance liquid crystal is
vulnerable to contamination. Such a contamination may
come from the sealing material of the liquid crystal
display device or from the molecular alignment film.
15 Once the liquid crystal is contaminated, the
representation performance of the liquid crystal
display device is severely deteriorated.

Further, it should be noted that the
electric field 13B induced in the liquid crystal layer
20 13 in the driving state of the liquid crystal display
device is not exactly parallel to the plane of the
liquid crystal layer 13 in the vicinity of the
electrode 14A or 14B. This means that the electric
field component parallel to the plane of the liquid
25 crystal layer 13 becomes small and the response speed
of the liquid crystal molecules 13A becomes
accordingly small in the vicinity of the electrodes
14A and 14B.

Thus, there is an acute demand of improved
30 performance for the conventional IPS liquid display
device.

SUMMARY OF THE INVENTION

Accordingly, it is a general object of the
35 present invention to provide a liquid crystal display
device wherein the foregoing problems are eliminated.

The present invention provides a liquid

1 crystal display device, comprising:
first and second, mutually opposing
substrates;
a liquid crystal layer confined between said
5 first and second substrates;
an electrode formed on said first substrate
so as to create an electric field acting generally
parallel to a plane of said liquid crystal layer; and
a plurality of pixels being defined in said
10 liquid crystal layer,
each of said plurality of pixels including
therein a plurality of domains having respective
orientations for liquid crystal molecules, such that
said orientation is different between a domain and
15 another domain within said plane of said liquid
crystal layer.

According to the present invention, it is
possible to improve the response speed of the IPS
liquid crystal display device, by providing domains in
20 each of the pixels in the liquid crystal layer such
that the molecular orientation is different between a
domain and another domain when compared in the plane
of the liquid crystal layer. More specifically, the
present invention achieves the desired improvement of
25 response by twisting the liquid crystal molecules, in
the non-activated state of the liquid crystal display
device, such that the molecular orientation of the
liquid crystal molecules in the domain adjacent to the
electrode is closer to the molecular orientation in
30 the activated state of the liquid crystal display
device, as compared with the molecular orientation of
the liquid crystal molecules in the domain far from
the electrode. As a result, the liquid crystal
molecules adjacent to the electrode are aligned in the
35 activated direction immediately upon application of
the driving voltage to the electrode, in spite of the
fact that the electric field component included in the

1 plane of the liquid crystal layer is small in the
vicinity of the electrode.

Other objects and further features of the
present invention will become apparent from the
5 following detailed description when read in
conjunction with the attached drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS.1A and 1B are diagrams showing the
10 principle of a conventional IPS liquid crystal display
device;

FIGS.2A and 2B are diagrams showing the
construction of an IPS liquid crystal display device
according to first and second embodiments of the
15 present invention;

FIGS.3A and 3B are diagrams showing the
construction of an IPS liquid crystal display device
of the first embodiment;

FIGS.4A and 4B are diagrams showing a
20 modification of the IPS liquid crystal display device
of the first embodiment;

FIG.5 is a diagram showing the construction
of an IPS liquid crystal display device according to a
third embodiment of the present invention;

25 FIG.6 is a diagram showing the electro-optic
property of a conventional IPS liquid crystal display
device;

FIGS.7A and 7B are diagrams showing the
principle of an IPS liquid crystal display device
30 according to a fourth embodiment of the present
invention;

FIGS.8A and 8B are diagrams showing examples
of the electrodes used in the IPS liquid crystal
display device of the fourth embodiment;

35 FIGS.9A and 9B are diagrams further examples
of the electrodes used in the IPS liquid crystal
display device of the fourth embodiment;

1 FIGS.10A and 10B are diagrams showing the
viewing angle of the IPS liquid crystal display device
of the fourth embodiment in comparison with the
viewing angle of a conventional IPS liquid crystal
5 display device;

FIG.11 is a diagram showing another
construction of the IPS liquid crystal display device
of the fourth embodiment of the present invention;

FIG.12 is a diagram showing further
10 construction of the IPS liquid crystal display device
of the fourth embodiment; and

FIG.13 is a diagram showing still further
construction of the IPS liquid crystal display device
of the fourth embodiment.

15

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT
[FIRST EMBODIMENT]

FIGS.2A and 2B show the construction of an
IPS liquid crystal display device 20 according to a
20 first embodiment of the present invention.

Referring to FIG.2A, the liquid crystal
display device 20 includes a pair of mutually opposing
glass substrates 21 and 22, and a liquid crystal layer
23 is confined in a space formed between the glass
25 substrates 21 and 22. Further, the glass substrate 21
carries thereon a TFT (thin-film transistor) having a
gate electrode 24A, a pixel electrode 24B and a source
electrode 24C.

As represented in FIG.2A, the gate electrode
30 24A is covered by an insulation film 21A provided on
the glass substrate 21 and constituting the gate
insulation film of the TFT, wherein the foregoing
pixel electrode 24B and the source electrode 24C are
both formed on the insulation film 21A. Further, the
35 glass substrate 21 carries thereon an opposing
electrode 24D with a separation from the pixel
electrode 24B in the state that the opposing electrode

1 24D is covered by the insulation film 21A.

 It should be noted that the foregoing TFT is covered by a molecular alignment film 21B provided on the insulation film 21A, and the liquid crystal layer
5 23 is formed in an intimate contact with the molecular alignment film 21B. In the foregoing construction, a pixel region is defined between the pixel electrode 24B and the opposing electrode 24D.

 On the opposing substrate 22, on the other
10 hand, there is provided an opaque mask pattern 22A in correspondence to the TFT on the substrate 21, and a color filter 22C is formed on the substrate 22 adjacent to the opaque mask pattern 22A, such that the color filter 22C is located in correspondence to the
15 pixel region defined in the substrate 21 between the electrode 24B and the electrode 24D. The color filter 22C thus formed is covered by a molecular alignment film 22B, wherein the molecular alignment film 22B is provided such that the molecular alignment film 22B
20 makes an intimate contact with the liquid crystal layer 23 in the state that the molecular alignment film 22B faces the molecular alignment film 21B formed on the glass substrate 21.

 Further, the liquid crystal display device
25 20 includes a polarizer 25 on the lower surface of the glass substrate 21 and an analyzer 26 on the top surface of the glass substrate 22 in a crossed Nicol state in which the optical absorption axes of the polarizer 25 and the analyzer 26 intersect
30 perpendicularly.

 FIG.2B shows the electrode pattern of the liquid crystal display device 20 in a plan view.

 Referring to FIG.2B, each of the TFTs is formed at an intersection of a gate bus line which
35 corresponds to the gate electrode 24A and a source bus line which corresponds to the source electrode 24C, and the pixel electrode 24B and the opposing electrode

1 24D extend parallel with each other in the elongating
direction of the source bus line.

 In the liquid crystal display device 20
having such a construction, an electric field acting
5 generally parallel to the plane of the liquid crystal
layer 23 is induced between the pixel electrode 24B
and the opposing electrode 24D in response to the
turning-ON of the TFT, and the electric field thus
induced causes a change in the orientation of the
10 liquid crystal molecules 23A constituting the liquid
crystal layer 23 in the plane of the liquid crystal
layer 23. In response to such a change in the
orientation of the liquid crystal molecules, the
optical beam passing through the liquid crystal
15 display device 20 is turned on and off.

 FIG.3A shows the liquid crystal display
device 20 in a cross-section taken along a line A-A'
of FIG.2B, while FIG.3B shows a plan view
corresponding to FIG.3A.

20 Referring to FIGS.3A and 3B, there are
formed pixel regions 23_1 and 23_2 between the pixel
electrode 24B and the opposing electrodes 24D formed
adjacent to the pixel electrode 24B at respective
opposite sides thereof, wherein each of the pixel
25 regions 23_1 and 23_2 includes a pair of sub-regions or
domains θ_2 , one adjacent to the electrode 24B and the
other adjacent to the electrode 24D, and another sub-
region or domain θ_1 is formed in the same pixel region
 23_1 or 23_2 between a pair of the sub-regions θ_2 thus
30 formed. Thus, each of the pixel region 23_1 or 23_2 of
the present embodiment has a domain structure formed
of the sub-regions θ_1 and θ_2 .

 As represented in FIG.3B, the liquid crystal
molecules 23A, more specifically the elongating
35 direction of the liquid crystal molecules 23A, forms
an angle θ_1 of typically about 15° in the non-
activated state of the liquid crystal display device

1 with respect to the elongating direction of the pixel
electrode 24B, and thus the elongating direction of
the source bus line 24C, in the sub-region θ_1 . On the
other hand, in the sub-region θ_2 , the liquid crystal
5 molecules 23A forms an angle θ_2 of typically about 30°
with respect to the elongating direction of the source
bus line 24C in the non-activated state of the liquid
crystal display device.

Thus, it can be seen that the liquid crystal
10 molecules 23A form, in the non-activated state of the
liquid crystal display device 20, an angle of about
 75° with respect to the direction of the electric
field E formed between the electrode 24B and the
electrode 24D in the sub-region θ_1 , while the angle of
15 the liquid crystal molecules 23A with respect to the
electric field E becomes about 60° in the sub-region
 θ_2 .

By setting the direction of the liquid
crystal molecules 23A for the non-activated state of
20 the liquid crystal display device 20 to be closer to
the activated direction of the liquid crystal
molecules 23A, which is realized in the activated
state of the liquid crystal display device 20, it
becomes possible to align the liquid crystal molecules
25 quickly in the desired activated direction
corresponding to the activated state of the liquid
crystal display device 20 upon the activation of the
liquid crystal display device 20. In other words, the
liquid crystal display device 20 of the present
30 embodiment shows an improved response speed.

In fact, it was confirmed, in an IPS liquid
crystal display device having a resolution of $640 \times$
480 pixels and constructed according to FIGS.3A and
3B, in that the sum of the turn-on response time t_{on}
35 and the turn-off response time t_{off} is reduced to 50
ms. It should be noted that this value is a
substantial improvement over the conventional value of

1 60 ms. In this experiment conducted by the inventor,
a liquid crystal mixture exclusively formed of a
fluoric liquid crystal component and a neutral liquid
5 molecular alignment film supplied from Japan Synthetic
Rubber, K.K. under the trade name of AL1054. The
foregoing liquid crystal mixture used in the
experiment has a dielectric anisotropy $\Delta\epsilon$ of 8.0 and
the initial resistivity of about $1 \times 10^{14} \Omega\text{cm}$.
10 Further, the sub-regions or domains θ_1 and θ_2 of
FIGS.3A and 3B are formed by a rubbing process
conducted under existence of a mask.

In the construction of FIGS.3A and 3B that
includes the sub-regions θ_1 and θ_2 , in which the
15 direction of alignment of the liquid crystal molecules
is changed between the sub-regions θ_1 and θ_2 , it is
inevitable that leakage of light occurs to some
extent. In view of this, it is preferable to set the
width of the sub-region θ_2 to be less than about $1 \mu\text{m}$.
20 In this case, the width of the sub-region θ_1 becomes $4 \mu\text{m}$
as represented in FIG.3B, assuming that the pixel
region 23_1 or 23_2 has a width of $6 \mu\text{m}$. Further, the
sub-region θ_2 may be covered by the opaque mask 22A
provided on the opposing substrate 26 for cutting the
25 leakage of the light caused in the sub-region θ_1 . In
this case, the sub-region θ_1 becomes the effective
pixel region. Smaller the sub-region θ_2 , larger than
the effective pixel region θ_1 .

In the construction of FIGS.3A and 3B, the
30 direction of alignment of the liquid crystal molecules
are set generally symmetric about the pixel electrode
24B in the pixel region 23_1 and the pixel region 23_2
that are disposed adjacent to the pixel electrode 24B.
By setting the direction of the liquid crystal
35 molecules as such, the viewing-angle characteristic of
the liquid crystal display device 20 is improved
further.

1 It is of course possible to align the liquid
crystal molecules in the same direction in the pixel
region 23_1 and in the pixel region 23_2 as represented
in FIGS.4A and 4B. In the construction of FIGS.4A and
5 4B, the domain structure of the pixel region 23_1 is
repeated in the pixel region 23_2 . As other features
of FIGS.4A and 4B are identical with those of FIGS.3A
and 3B, further description thereof will be omitted.

10 [SECOND EMBODIMENT]

Meanwhile, it is important to use a liquid
crystal having a large initial resistivity for the
liquid crystal layer 23 in order to secure a reliable
and stable operation of a liquid crystal display
15 device. On the other hand, the use of such a liquid
crystal of large initial resistivity in an IPS liquid
crystal display device tends to cause the problem of
sticking of images or afterimage as mentioned
previously.

20 In order to overcome the foregoing problem,
the present embodiment reduces the resistance of the
liquid crystal, which has a large initial resistivity,
by exposing the molecular alignment films 21B and 22B
with a ultraviolet radiation at the time of
25 fabrication of the liquid crystal display device.
Thereby, by using a polarized ultraviolet beam for
this purpose, it is possible to set the direction of
alignment of the liquid crystal molecules, which is
caused by the molecular alignment films 21B and 22B,
30 such that the liquid crystal molecules are aligned
coincident to the plane of polarization of the
polarized ultraviolet beam.

TABLE I below shows the result of
experiments with regard to the sticking of images
35 conducted on the IPS liquid crystal display device 20
of FIGS.2A and 2B for the case in which a polarized
ultraviolet beam is applied to the molecular alignment

1 films 21B and 22B.

TABLE I

5		EXP-1	EXP-2	EXP-3	COMP
	INITIAL	GOOD	GOOD	GOOD	GOOD
	AFTER 12H	GOOD	GOOD	GOOD	BAD
	AFTER 24H	FAIR	GOOD	GOOD	BAD
10	RUNNING	GOOD	GOOD	GOOD	GOOD

Referring to TABLE I, the Experiment-1 (EXP-1) is conducted by using the AL1054 molecular alignment film of Japan Synthetic Rubber, K.K. for the molecular alignment films 21B and 22B and irradiating thereto a polarized ultraviolet beam uniformly with a dose of about 6 J/cm^2 . The glass substrates carrying the molecular alignment films 21B and 22B thus processed, are used to assemble a liquid crystal panel, and the liquid crystal display device 20 is formed by introducing a liquid crystal mixture of a high-resistivity liquid crystal into the liquid crystal panel as the liquid crystal layer 13. The liquid crystal mixture used in the Experiment-1 contains exclusively a fluoric liquid crystal component and a neutral liquid crystal component and is characterized by a dielectric anisotropy $\Delta\epsilon$ of 8.0 and the initial resistivity of about $1 \times 10^{14} \Omega\text{cm}$. In the liquid crystal display device 20 used in this experiment, there is no domain structure formed, contrary to the embodiment of FIGS.3A and 3B or FIGS.4A and 4B.

For the sake of comparison, a liquid crystal display device is formed with the same structure as the liquid crystal display device 20 of FIGS.2A and 2B, except that the ultraviolet radiation is omitted.

1 In this Comparative Experiment, the molecular
alignment films 21B and 22B are subjected to a rubbing
process.

5 In the experiment of TABLE I, the degree of
image sticking was evaluated visually after displaying
a stationary pattern image at 50°C continuously for 12
hours and 24 hours. Further, a running test was
conducted in which the existence of non-uniformity in
image representation was examined after continuous
10 running operation for 500 hours at 50°C.

Referring to TABLE I, it can be seen that a
distinct sticking of images was observed in the
Comparative Experiment after 12 hours or 24 hours of
operation. On the other hand, in the case of the
15 Experiment-1, no image sticking was observed at all
after 12 hours. Further, no image sticking was
observed after 24 hours, as long as the liquid crystal
display device is viewed from the front direction.
When viewed from an oblique direction, on the other
20 hand, appearance of a minor image sticking was
observed in the experiment-1 when the liquid crystal
display device is viewed from an oblique direction.

In the Experiment-2 (EXP-2), on the other
hand, the sub-region θ_1 of FIGS.3A and 3B was exposed
25 to the polarized ultraviolet beam with a dose of about
 6 J/cm^2 while the sub-region θ_2 was exposed to the
same polarized ultraviolet beam with a dose of about
 12 J/cm^2 . In this experiment, the polarization plane
was not changed between the case of exposing the sub-
30 region θ_1 and the case of exposing the sub-region θ_2 .
Thus, the direction of liquid crystal molecular
alignment is the same between the sub-region θ_1 and
the sub-region θ_2 in the Experiment-2.

As will be noted from TABLE I, the problem
35 of image sticking was eliminated in any of the initial
state, after 12 hours, and after 24 hours. Further,
no image sticking or non-uniformity was observed in

1 the running test.

In the Experiment-3 (EXP-3), a process similar to the process of the Experiment-2 is conducted, except that a mask process is used in the
5 step of exposing the sub-region θ_2 with the polarized ultraviolet beam, wherein the polarization plane of the polarized ultraviolet beam is changed when exposing the sub-region θ_2 with respect to the case of exposing the sub-region θ_1 . Thus, a domain structure
10 similar to the one shown in FIGS.3A and 3B or 4A and 4B is formed in the liquid crystal layer 23 in the Experiment-3. In the Experiment-3, too, the exposure dose of the sub-region θ_2 is set to $12\text{J}/\text{cm}^2$, which is twice as large as the exposure dose used for the sub-
15 region θ_1 .

As can be seen from TABLE I, the problem of image sticking is totally eliminated in any of the initial state, after 12 hours, after 24 hours, and the running test for 500 hours. It should be noted that
20 the liquid crystal display device used in the Experiment-3 provides an improved response speed due to the domain structure represented in FIGS.3A and 3B or FIGS.4A and 4B.

25 [THIRD EMBODIMENT]

FIG.5 shows the construction of a liquid crystal display device 30 according to a third embodiment of the present invention, wherein those parts corresponding to the parts described previously
30 are designated by the same reference numerals and the description thereof will be omitted.

Referring to FIG.5, the liquid crystal display device 30 uses a high-resistivity liquid crystal mixture containing therein exclusively a
35 fluoric liquid crystal component and a neutral liquid crystal component for the liquid crystal layer 23, wherein the resistance of the liquid crystal layer 23

1 is reduced by introducing therein an impurity material.

5 In the example of FIG.5, an epoxy resin is provided on the surface of the spacers 31 that are distributed uniformly in the liquid crystal layer 23 so that an impurity material is released from the epoxy resin into the liquid crystal layer 23. In the case such spacers are introduced into 100g of the liquid crystal mixture having a resistivity of about $1 \times 10^{14} \Omega \text{cm}$ with an amount of 0.003g and held at 100°C for 60 minutes, the resistivity of the liquid crystal layer 13 is reduced to about $1 \times 10^{12} \Omega \text{cm}$.

15 Thus, in the present embodiment, an SVGA-TFT liquid crystal panel of the 11.3-inch size was fabricated based on the liquid crystal display device 30 of FIG.5 and the sticking of images was examined for the liquid crystal display panel thus fabricated. According to the test conducted by the inventor, it was confirmed that a result similar to the Experiment-1 or Experiment-2 of TABLE I is obtained even in such a case the molecular alignment films 21B and 22B are processed by a rubbing process.

25 It should be noted that the desired decrease of the resistivity of the liquid crystal layer 23 is not limited to the introduction of impurity component released from the surface of the spacer 31 shown in FIG.5, but may be achieved also by admixing a liquid crystal of low initial resistance such as the liquid crystal containing a CN component to the liquid crystal mixture of the liquid crystal layer 23. As a result of decrease of the resistivity in the liquid crystal layer 23, the problem of image sticking of the liquid crystal display device is effectively eliminated.

35 In the present invention, it should be noted that the liquid crystal mixture used for the liquid crystal layer 23 per se has a large resistance. Thus,

1 the deterioration of the liquid crystal layer 23
caused by the dissolution of the seal is suppressed
and the liquid crystal display device shows an
improved, long-term reliability.

5

[FOURTH EMBODIMENT]

FIG.6 shows the electro-optic
characteristic, more specifically the relationship
between the driving voltage V and the transmittance T
10 of a typical conventional IPS liquid crystal display
device. In FIG.6, the broken line shows the
transmittance T as viewed from the front direction of
the liquid crystal display device, while the
continuous line shows the transmittance T as viewed
15 from an oblique direction in which the azimuth angle
is 135° and the polar angle is 60°.

Referring to FIG.6, it can be seen that
there appears a reversal in the relationship between
the transmittance T and the driving voltage V, in the
20 region where the driving voltage V is less than about
3 V, in that the transmittance T decreases with
increasing driving voltage V.

FIG.7A shows the relationship between the
transmittance T and the driving voltage V of an IPS
25 liquid crystal display device having an interdigital
electrode of FIG.7B, wherein FIG.7A shows the
relationship in an enlarged scale in the voltage range
lower than 3V. It should be noted that the
interdigital electrode of FIG.7B includes the pixel
30 electrode 24B and the opposing electrode 24D of FIG.2B
in the state that each of the electrodes 24B and 24D
has a plurality of electrode fingers extending
parallel with each other.

Referring to FIG.7A, it can be seen that,
35 while the driving voltage V corresponding to the
maximum inversion of the transmittance T changes
between the case in which the interval between the

1 electrode fingers is set to 6 μm and the case in which
the interval is set to 15 μm , the average
transmittance of these two cases shows a reduced
magnitude of inversion as a result of the
5 superposition of the two characteristic curves.

Thus, in the present embodiment, a plurality
of regions of mutually different electro-optic
characteristics are formed in each of the pixels of
the IPS liquid crystal display 20 of FIG.2A, so that
10 the electro-optic characteristics are averaged in each
pixel. As a result of the superposition of the
electro-optic characteristics, the relationship
between the transmittance T and the driving voltage V
is averaged, and the problem of inversion of contrast,
15 which tends to occur when the liquid crystal display
device is viewed from an oblique direction, is
minimized.

FIG.8A shows the construction of an
interdigital electrode used in the present embodiment
20 for forming the regions of different electro-optic
characteristics in a pixel.

Referring to FIG.8A, the interdigital
electrode has a construction generally similar to the
interdigital electrode of FIG.7B, except that the
25 pixel electrode 24B and the opposing electrode 24D are
displaced laterally to each other. As a result of
such a laterally displaced construction of the
electrodes 24B and 24D, there are formed a first
electrode interval W_1 and a second electrode interval
30 W_2 larger than the first electrode interval W_1 in the
interdigital electrode. Thus, by using the
interdigital electrode of FIG.8A, it becomes possible
to form the regions of different electro-optic
properties in each pixel of the liquid crystal layer
35 23. Thereby, the liquid crystal display device of the
present embodiment provides an improved viewing angle
characteristic in which the inversion of contrast is

1 minimized.

It will be noted that a similar result of improved viewing angle characteristic is achieved also by using the interdigital electrode of FIG.8B.

5 FIG.9A shows an example of the interdigital electrode for use in an IPS liquid crystal display device, in which it will be noted that the electrode fingers 24b of the pixel electrode 24B are formed to have a tapered shape. Further, FIG.9B shows another
10 example in which the electrode fingers 24b of the pixel electrode 24B are formed to have a sawtooth pattern. In the example of FIG.9B, the electrode fingers 24d of the opposing electrode 24D also have a sawtooth pattern. By using the interdigital electrode
15 of FIG.9B, the electro-optic characteristics are also averaged similarly to the example of FIG.9A and the viewing angle characteristic of the IPS liquid crystal display device is improved.

FIGS.10A and 10B are diagrams showing the
20 viewing-angle characteristics of the IPS liquid crystal display device of 15-inch size having a resolution of 1024 x 765, wherein FIG.10A corresponds to the case in which the interdigital electrode of FIG.7B is used, while FIG.10B corresponds to the case
25 in which the interdigital electrode of FIG.8A is used. In FIGS.10A and 10B, the contours represent the contrast ratio CR.

Referring to FIG.10A, it can be seen that the liquid crystal display device has an excellent
30 viewing angle characteristic, while it is still noted that there is an inversion of contrast occurring in the azimuth angle of 45°.

In the case of FIG.10B, on the other hand, it can be seen that the contrast inversion occurring
35 in the azimuth angle of 45° is vanished.

It should be noted that there are other various ways to form plurality of regions of different

1 electro-optic characteristics in the pixel region.
For example, FIG.11 shows the case in which the
thickness of the liquid crystal layer 13 is changed
within a pixel, wherein it should be noted that FIG.11
5 represents the cross-section crossing the pixel
electrode 24B or the opposing electrode 24D in the
direction of the source bus line. In FIG.11, those
parts corresponding to the parts described previously
are designated by the same reference numerals and
10 further description thereof will be omitted.

FIG.12 shows an example in which the
direction of the liquid crystal molecules in the non-
activated state of the liquid crystal display device
is changed within a pixel. It should be noted that
15 FIG.12 represents the cross-section crossing the pixel
electrode 24B or the opposing electrode 24D in the
direction of the source bus line. In FIG.12, too,
those parts corresponding to the parts described
previously are designated by the same reference
20 numerals and further description thereof will be
omitted.

Further, FIG.13 shows another example of
achieving the effect of the present embodiment by
changing the tilting direction of the liquid crystal
25 molecules within a pixel. It should be noted that
FIG.13 represents the cross-section crossing the pixel
electrode 24B or the opposing electrode 24D in the
direction of the source bus line. In FIG.13, too,
those parts corresponding to the parts described
30 previously are designated by the same reference
numerals and further description thereof will be
omitted.

Further, the present invention is not
limited to the embodiments described heretofore, but
35 various variations and modifications may be made
without departing from the scope of the present
invention.

1 WHAT IS CLAIMED IS

5

1. A liquid crystal display device,
comprising:

first and second, mutually opposing
substrates;

10 a liquid crystal layer confined between said
first and second substrates;

an electrode formed on said first substrate
so as to create an electric field acting generally
parallel to a plane of said liquid crystal layer; and

15 a plurality of pixels being defined in said
liquid crystal layer,

each of said plurality of pixels including
therein a plurality of domains having respective
orientations for liquid crystal molecules, such that
20 said orientation is different between a domain and
another domain within said plane of said liquid
crystal layer.

25

2. A liquid crystal display device as
claimed in claim 1, wherein each of said plurality of
pixels is formed in correspondence to said electrode,
30 said electrode comprising a first electrode and a
second electrode formed on said first substrate with a
mutual separation, said plurality of domains including
a first domain adjacent to said first electrode, a
second domain adjacent to said second electrode, and a
35 third domain intervening between said first domain and
said second domain, said liquid crystal molecules
aligning, in said first and second domains, in a first

1 direction forming a first angle with respect to a
direction of said electric field within said plane of
said liquid crystal layer, said liquid crystal
molecules aligning, in said third domain, in a second
5 direction forming a second angle with respect to said
direction of said electric field within said plane of
said liquid crystal layer, wherein said second angle
is larger than said first angle.

10

3. A liquid crystal display device as
claimed in claim 2, wherein said second angle is
15 larger than about 50° and smaller than about 75°.

20 4. A liquid crystal display device as
claimed in claim 2, wherein said first and second
electrodes extend parallel with each other, said first
and second directions being in a symmetric
relationship between a pair of mutually neighboring
25 pixels with respect to an elongating direction of said
first and second electrodes.

30

5. A liquid crystal display device as
claimed in claim 1, wherein said liquid crystal layer
has an initial resistivity of about $1 \times 10^{13} \Omega \text{cm}$ or
more.

35

1 6. A liquid crystal display device as
claimed in claim 5, wherein said liquid crystal layer
has a resistivity substantially smaller than said
initial resistivity.

5

 7. A liquid crystal display device,
10 comprising:
 first and second, mutually opposing
 substrates;
 a liquid crystal layer confined between said
 first and second substrates;
15 an electrode provided on said first
 substrate so as to create an electric field acting
 generally parallel to a plane of said liquid crystal
 layer; and
 a spacer member disposed between said first
20 and second substrates,
 said liquid crystal layer being formed of a
 liquid crystal having an initial resistivity of about
 $1 \times 10^{14} \Omega \text{cm}$,
 said spacer releasing an impurity to said
25 liquid crystal layer.

30 8. A liquid crystal display device as
claimed in claim 7, wherein said spacer carries an
epoxy resin on a surface thereof.

35

 9. A liquid crystal display device as

1 claimed in claim 7, wherein said liquid crystal layer
has an initial resistivity of about $1 \times 10^{13} \Omega \text{cm}$ or
more.

5

10. A liquid crystal display device as
claimed in claim 9, wherein said liquid crystal layer
10 has a resistivity substantially smaller than said
initial resistivity.

15

11. A liquid crystal display device,
comprising:

first and second, mutually opposing
substrates;

20 a liquid crystal layer confined between said
first and second substrates;

an electrode formed on said first substrate
so as to create an electric field acting generally
parallel to a plane of said liquid crystal layer; and

25 a plurality of pixels being defined in said
liquid crystal layer,

each of said plurality of pixels including a
plurality of domains having respective, mutually
different electro-optic properties.

30

12. A liquid crystal display device as
35 claimed in claim 11, wherein, in each of said pixels,
said electrode comprises an interdigital electrode
carrying a plurality of electrode fingers, said

1 plurality of electrode fingers being formed with an
interval which changes between an electrode finger
pair and a different electrode finger pair.

5

13. A liquid crystal display device as
claimed in claim 11, wherein said electrode comprises
10 an interdigital electrode carrying a plurality of
electrode fingers, an interval of said electrode
fingers being changed in each of said pixels.

15

14. A liquid crystal display device as
claimed in claim 11, wherein said electrode comprises
an interdigital electrode carrying a plurality of
20 electrode fingers, said plurality of electrode fingers
having respective, mutually different widths.

25

15. A liquid crystal display device as
claimed in claim 11, wherein said liquid crystal layer
has, in each of said plurality of pixels, a thickness
that changes in a direction perpendicular to a
30 direction of said electric field acting generally
parallel to said plane of said liquid crystal layer.

35

16. A liquid crystal display device as
claimed in claim 11, wherein said liquid crystal layer

1 comprises liquid crystal molecules such that said
liquid crystal molecules change an alignment direction
thereof in a direction generally perpendicular to a
direction of said electric field acting generally
5 parallel to said plane of said liquid crystal layer.

10 17. A liquid crystal display device as
claimed in claim 11, wherein said liquid crystal layer
comprises liquid crystal molecules such that said
liquid crystal molecules change a tilt angle thereof
in a direction generally perpendicular to a direction
15 of said electric field acting generally parallel to
said plane of said liquid crystal layer.

20 18. A method of fabricating a liquid
crystal display device, said liquid crystal display
device comprising: first and second, mutually opposing
substrates, a liquid crystal layer confined between
25 said first and second substrates, and an electrode
provided on said first substrate so as to create an
electric field acting generally in a plane of said
liquid crystal layer, said method comprising the step
of:

30 exposing a molecular alignment film formed
on each of said first and second substrates to a
polarized ultraviolet radiation.

35

19. A method as claimed in claim 18,

1 wherein said step of exposing said molecular alignment
film is conducted in a state that a plane of
polarization of said polarized ultraviolet radiation
coincides with a desired alignment direction of liquid
5 crystal molecules constituting said liquid crystal
layer.

10

20. A method as claimed in claim 18,
wherein said step of exposing said molecular alignment
film is conducted such that an exposure dose for a
non-pixel region is increased as compared with an
15 exposure dose for a pixel region.

20 21. A method of fabricating a liquid
crystal display device, said liquid crystal display
device comprising: first and second, mutually opposing
substrates, a liquid crystal layer confined between
said first and second substrates, and an electrode
25 provided on said first substrate so as to create an
electric field acting generally in a plane of said
liquid crystal layer, said method comprising the step
of:

introducing an impurity into said liquid
30 crystal layer.

35

1 ABSTRACT OF THE DISCLOSURE

 A liquid crystal display device includes a
liquid crystal layer confined between first and second
substrates, an electrode formed on the first substrate
5 so as to create an electric field acting generally
parallel to a plane of the liquid crystal layer, and a
plurality of pixels being defined in the liquid
crystal layer, wherein each of the pixels includes
therein a plurality of domains having respective
10 orientations for liquid crystal molecules, such that
the orientation is different between a domain and
another domain within the plane of the liquid crystal
layer.

15

20

25

30

35

FIG.1A

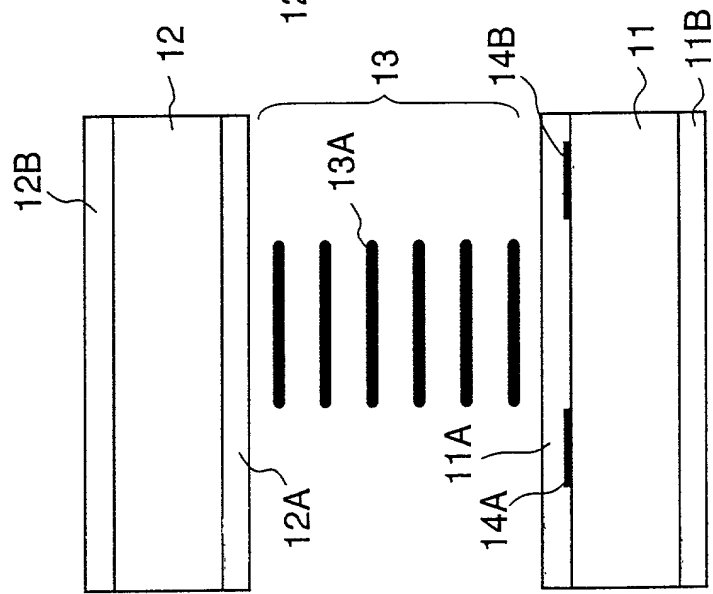


FIG.1B

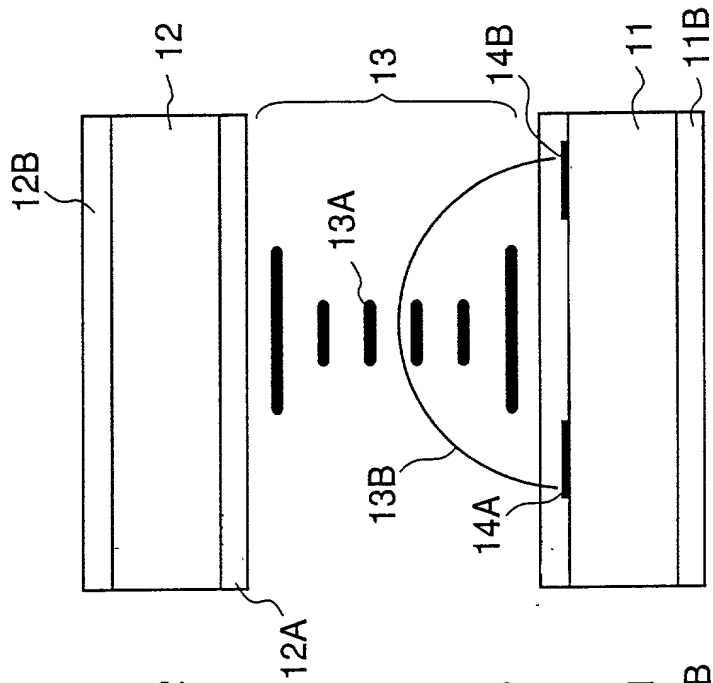


FIG.2A

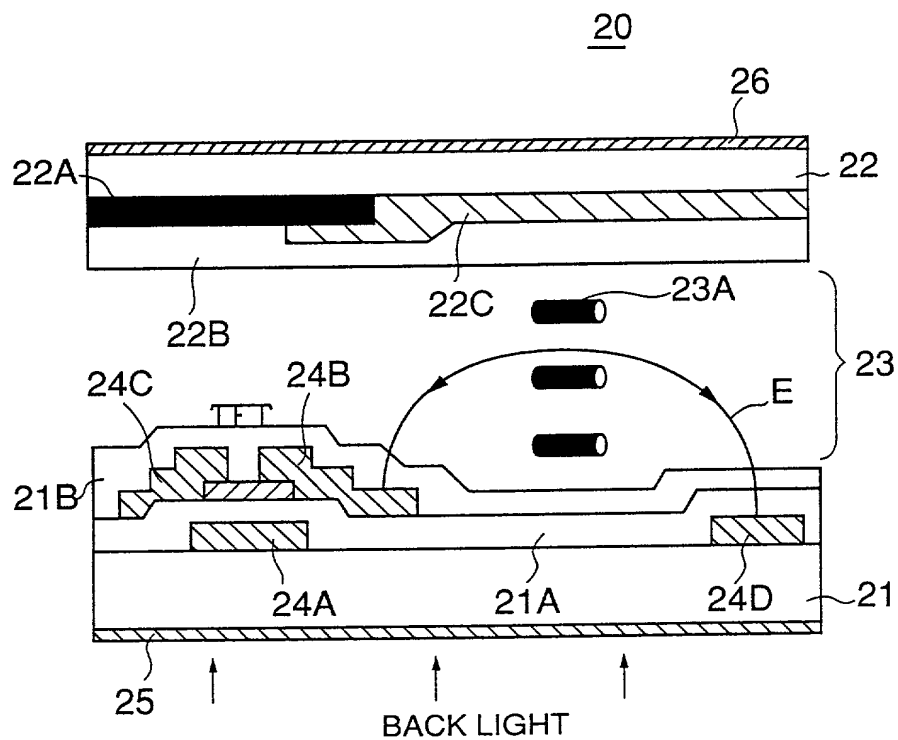
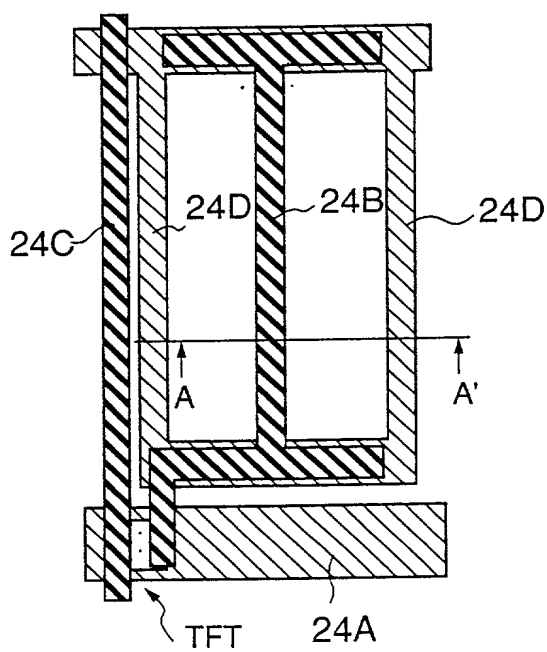


FIG.2B



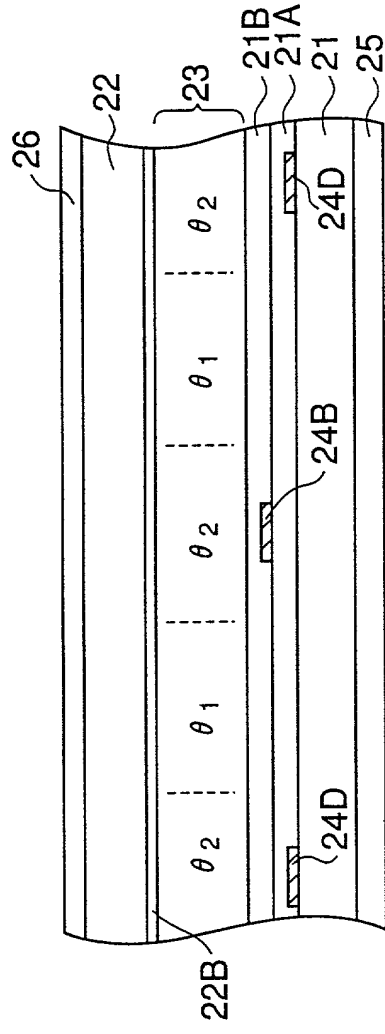


FIG. 3A

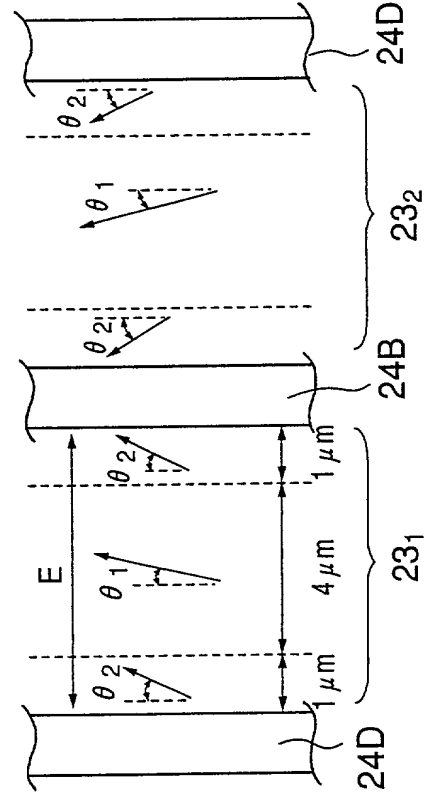


FIG. 3B

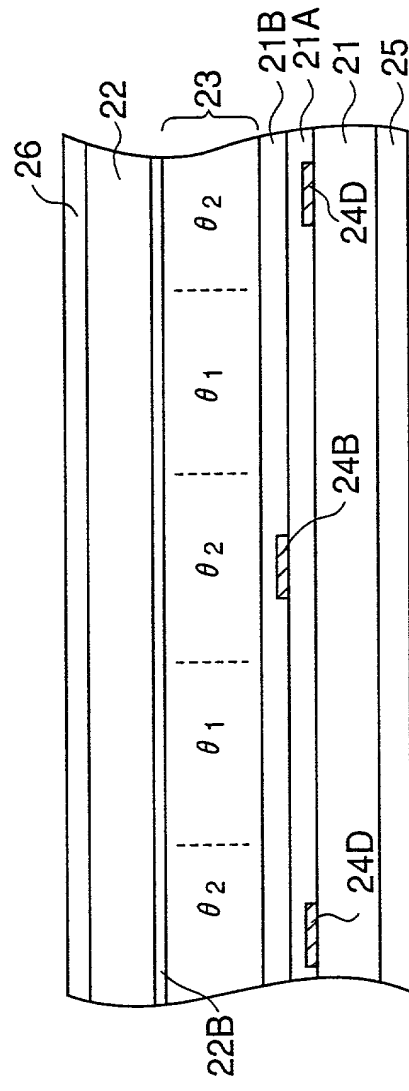


FIG. 4A

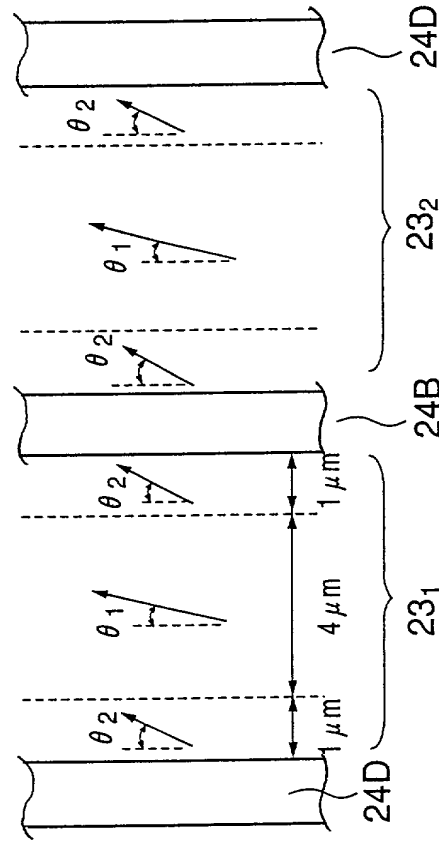


FIG. 4B

FIG. 5

30

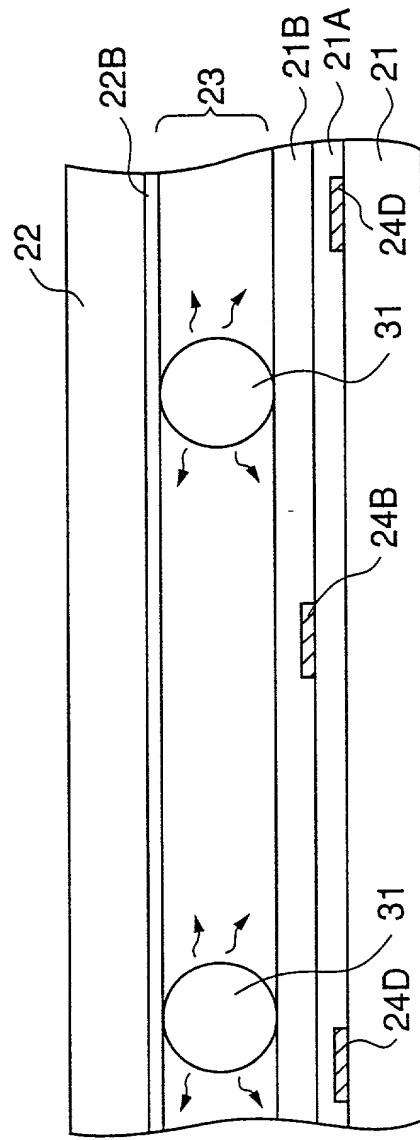


FIG.6

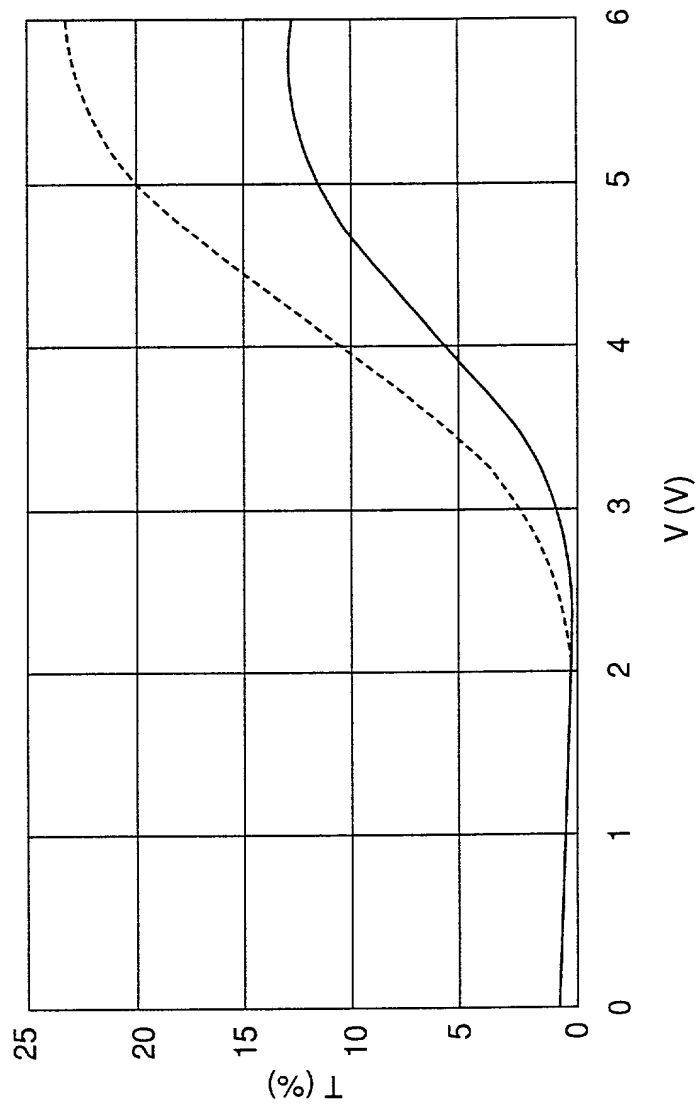


FIG.7A

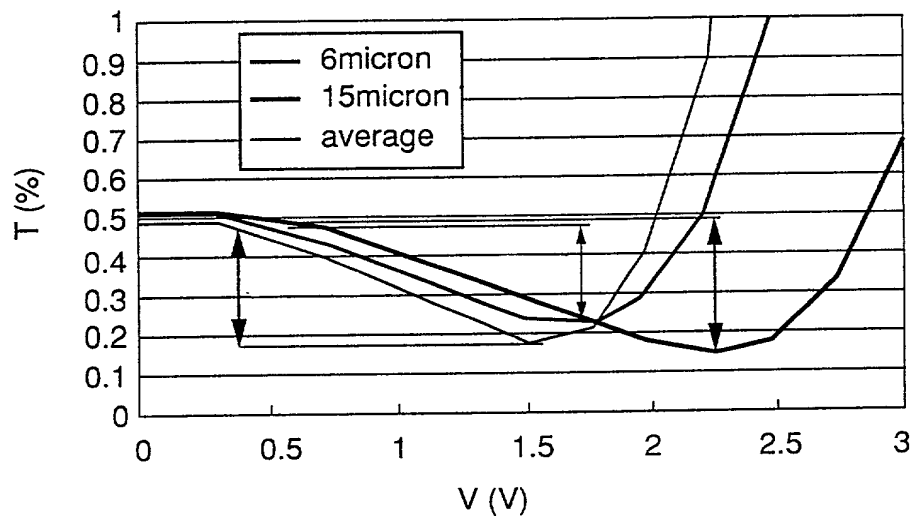


FIG.7B

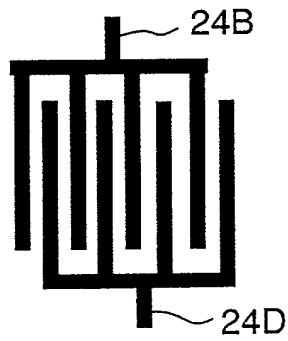


FIG.8A

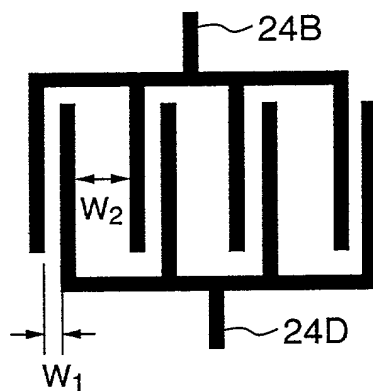


FIG.8B

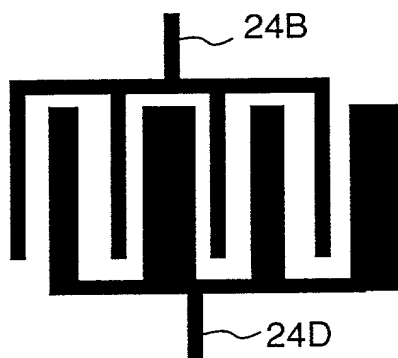


FIG.9A

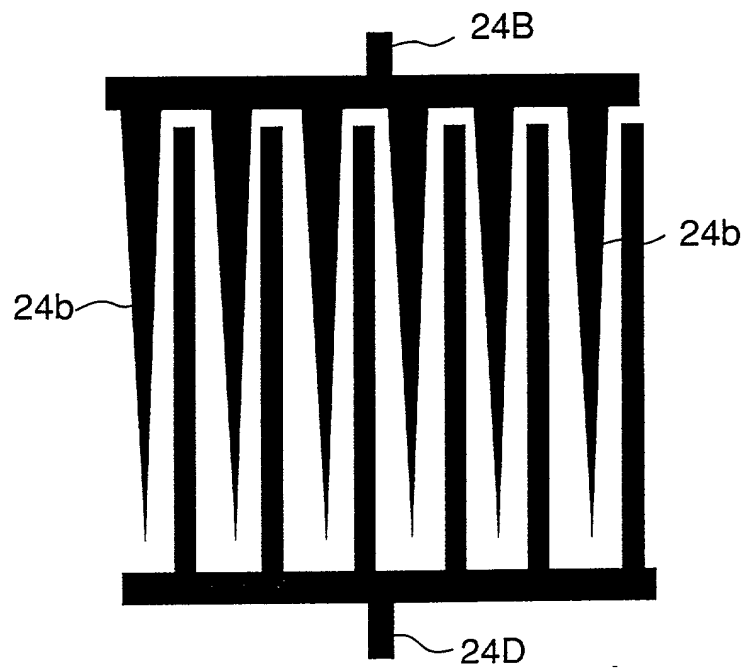


FIG.9B

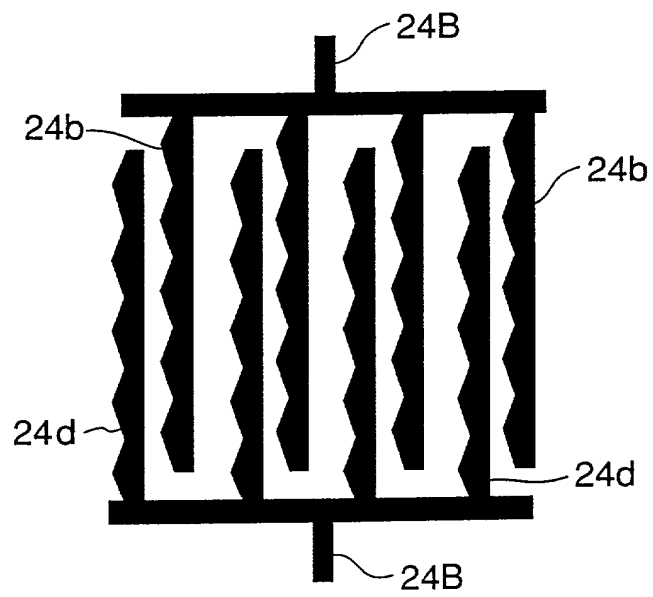


FIG.10A

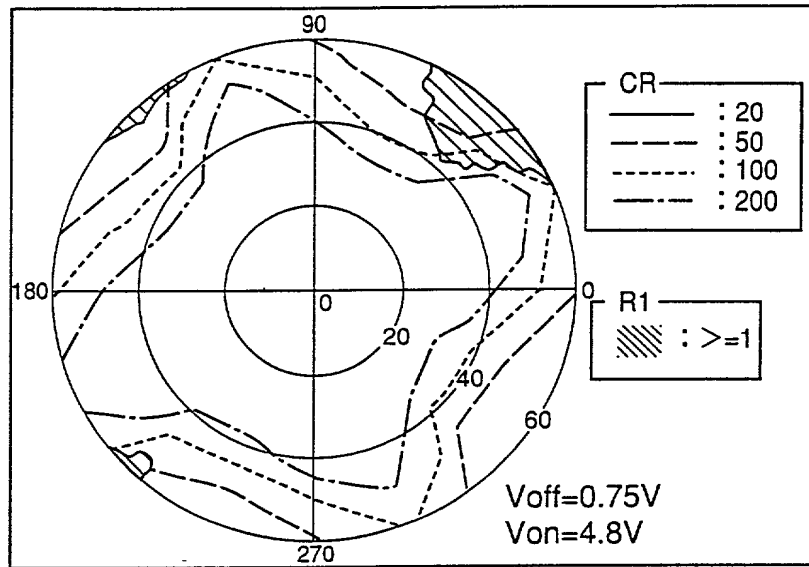


FIG.10B

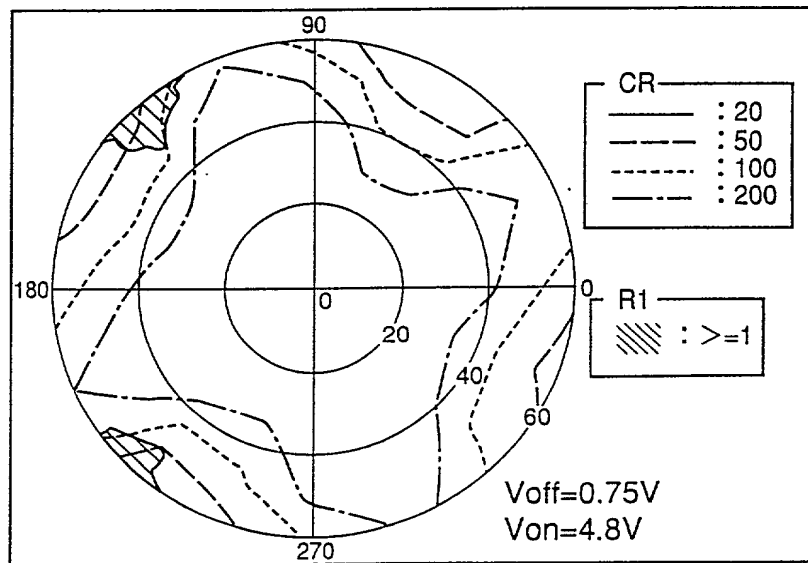


FIG.11

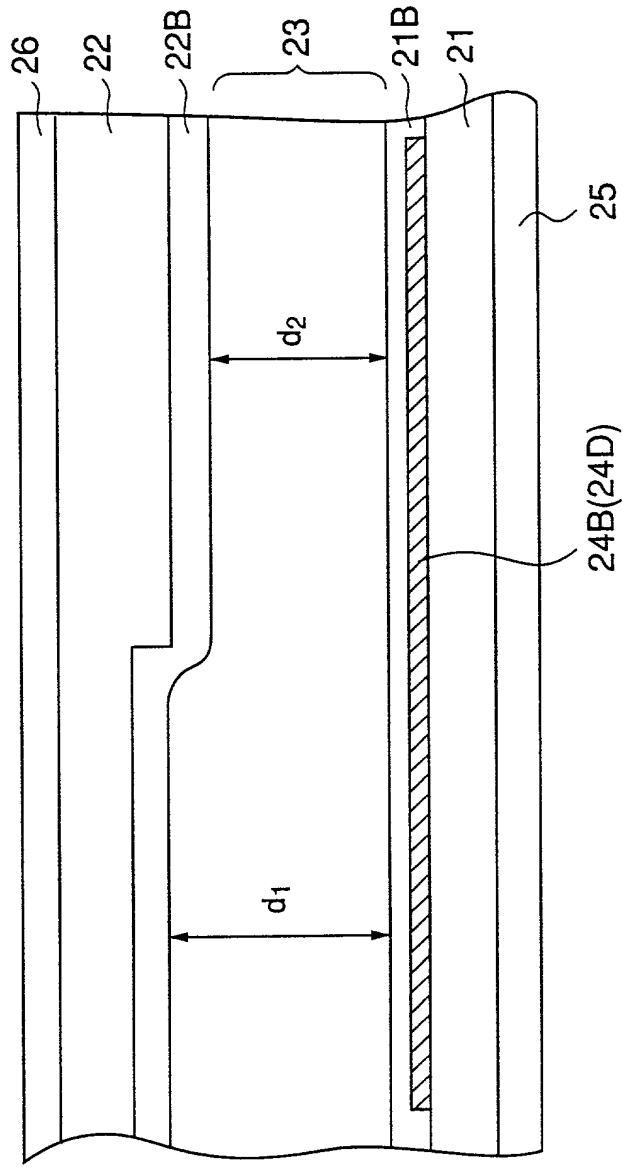


FIG.12

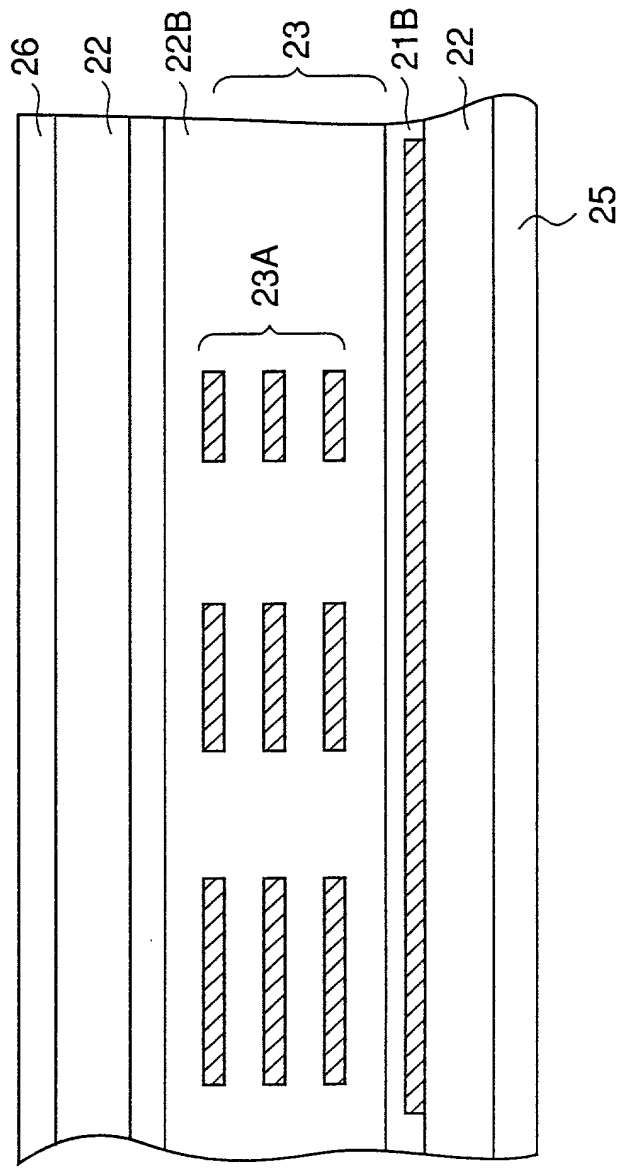
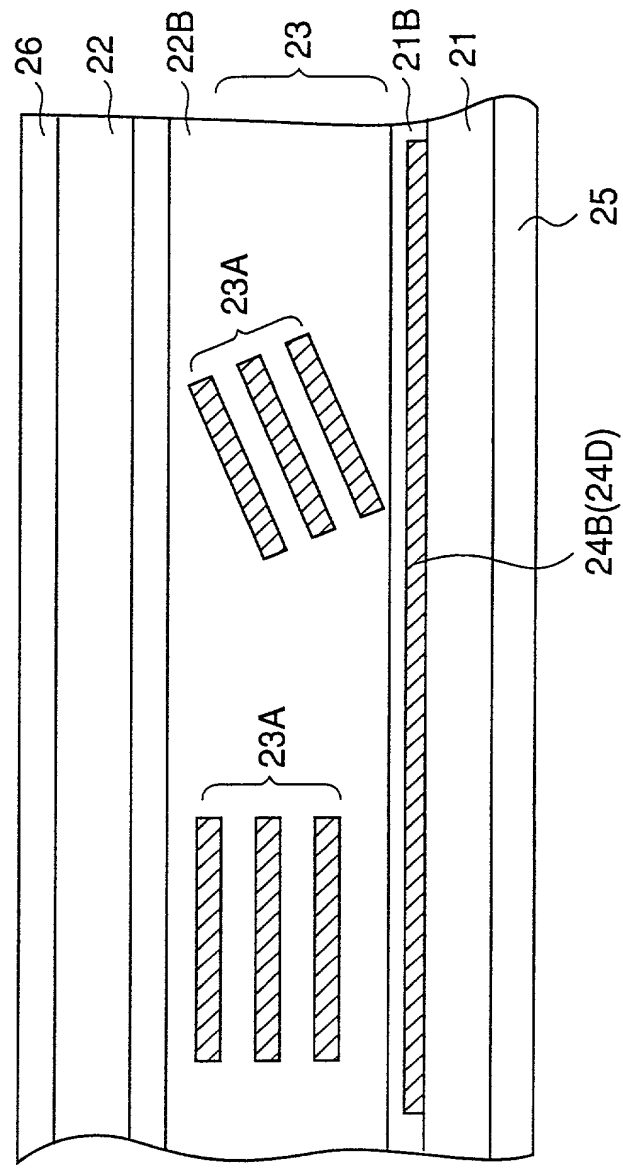


FIG.13



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Declaration and Power of Attorney For Patent Application

特許出願宣言書及び委任状

Japanese Language Declaration

日本語宣言書

下記の氏名の発明者として、私は以下の通り宣言します。

As a below named inventor, I hereby declare that:

私の住所、私書箱、国籍は下記の私の氏名の後に記載された通りです。

My residence, post office address and citizenship are as stated next to my name.

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I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled

IN-PLANE SWITCHING LIQUID CRYSTAL

DISPLAY DEVICE

上記発明の明細書（下記の欄でx印がついていない場合は、本書に添付）は、

the specification of which is attached hereto unless the following box is checked:

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（該当する場合）____に訂正されました。

☐ was filed on _____
as United States Application Number or
PCT International Application Number
_____ and was amended on
_____ (if applicable).

私は、特許請求範囲を含む上記訂正後の明細書を検討し、内容を理解していることをここに表明します。

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above.

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Prior Foreign Application(s) (Patent Application)

外国での先行出願
No. 10-324127

Japan

(Number)
(番号)

(Country)
(国名)

(Number)
(番号)

(Country)
(国名)

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(Application No.)
(出願番号)

(Filing Date)
(出願日)

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(Application No.)
(出願番号)

(Filing Date)
(出願日)

(Application No.)
(出願番号)

(Filing Date)
(出願日)

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I hereby claim foreign priority under Title 35, United States Code, Section 119 (a)-(d) or 365(b) of any foreign application(s) for patent or inventor's certificate, or 365(a) of any PCT International application which designated at least one country other than the United States, listed below and have also identified below, by checking the box, any foreign application for patent or inventor's certificate, or PCT International application having a filing date before that of the application on which priority is claimed.

Priority Not Claimed

優先権主張なし

13/November/1998

(Day/Month/Year Filed)
(出願年月日)

(Day/Month/Year Filed)
(出願年月日)

I hereby claim the benefit under Title 35, United States Code, Section 119(e) of any United States provisional application(s) listed below.

(Application No.)
(出願番号)

(Filing Date)
(出願日)

I hereby claim the benefit under Title 35, United States Code, Section 120 of any United States application(s), or 365(c) of any PCT International application designating the United States, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT International application in the manner provided by the first paragraph of Title 35, United States Code Section 112, I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations, Section 1.56 which became available between the filing date of the prior application and the national or PCT International filing date of application.

(Status: Patented, Pending, Abandoned)
(現況: 特許許可済、係属中、放棄済)

(Status: Patented, Pending, Abandoned)
(現況: 特許許可済、係属中、放棄済)

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Japanese Language Declaration (日本語宣言書)

委任状: 私は下記の発明者として、本出願に関する一切の
手続を米特許商標局に対して遂行する弁理士または代理人
として、下記の者を指名いたします。(弁理士、または代理
人の氏名及び登録番号を明記のこと)

POWER OF ATTORNEY: As a named inventor, I hereby appoint
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住所	Residence		
国籍	Citizenship		
私書箱	Post Office Address		
唯一または第一発明者名		Full name of fifth joint inventor, if any	
発明者の署名	日付	Inventor's signature	Date
住所	Residence		
国籍	Citizenship		
私書箱	Post Office Address		
第二共同発明者		Full name of sixth joint inventor, if any	
第二共同発明者	日付	Inventor's signature	Date
住所	Residence		
国籍	Citizenship		
私書箱	Post Office Address		

(第三以降の共同発明者についても同様に記載し、署名をすること)

(Supply similar information and signature for third and subsequent joint inventors.)